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An Overview of the "Greyscales" Lethality Assessment Methodology

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DSTO-TN-0982

ABSTRACT

Greyscales is a method for producing estimates of guided missile miss distance and missile warhead probability of kill. The associated computer code has been written to be portable and capable of being incorporated into a variety of simulations. The code has already been integrated into the Weapon Systems Division MECA and DUEL missile engagement simulations. It can also be integrated into larger scale simulations where multiple engagements between various platforms are represented. Greyscales provides an improved means of assessing missile/target engagements without resorting to computationally intensive missile and warhead/target interaction models. This brief report describes the greyscales approach.

RELEASE LIMITATION

Approved for public release

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Published by

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DSTO Defence Science and Technology Organisation
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Edinburgh South Australia 5111 Australia*

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AR-014-903
January 2011*

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An Overview of the "Greyscales" Lethality Assessment Methodology

Executive Summary

This short note presents an overview of the "Greyscales" method for estimating missile miss distance and probability of kill.

The representation of missiles in larger simulations can be rudimentary. Quite often a simple model is used to determine the time of intercept and a single probability of kill value is used for all engagement conditions. It follows that the outcome of an engagement is largely independent of the target and missile conditions at intercept. This type of assessment has limited value when the engagement states are highly dynamic, for example in air to air combat. A need exists to have improved representation of engagements so that some indication of the effect of combat parameters such as missile approach geometry, aircraft manoeuvre, launch range etc. can be obtained. Such information provides better insight into those procedures which give a tactical advantage as well as allowing better metrics to be used when assessing weapon alternatives or comparing weapon platforms.

Greyscales is a quick method for producing estimates of guided missile miss distance and missile warhead probability of kill. It provides an improved means of assessing missile/target engagements without resorting to computationally intensive missile and warhead/target interaction models. The associated computer code has been written to be portable and capable of being incorporated into a variety of simulations. The code has already been integrated into the Weapon Systems Division MECA and DUEL missile engagement simulations. It can also be integrated into larger scale simulations where multiple engagements between various platforms are represented.

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1. Introduction

In many applications a simplified missile / target engagement model is used to represent missile performance. These simplified models, often referred to as flyout models, have the advantage of being fast in execution, being relatively easy to construct and integrate into larger simulations. However, the information they provide is limited. This paper gives an overview of a method that aims to enhance the quality of representation of the missile / target interaction that is an intermediate step between the flyout model and the highly detailed simulation models that are expensive to construct, require detailed technical design data, and are often difficult to integrate into larger simulations.

2. Philosophy

Current weapon system simulations, particularly those embedded in larger simulations, often use a simple representation of a missile, often referred to as a flyout model, to determine the trajectory and a single value defining the probability of success/kill. As a result, the outcome of an engagement is largely independent of the target and missile conditions at intercept. This type of assessment has limited value when the engagement states are highly dynamic, for example in air to air combat. A need exists to have improved representation of engagements so that some indication of the effect of combat parameters such as missile approach geometry, aircraft manoeuvre, missile launch range etc. can be obtained. Such information provides better insight into those procedures which give a tactical advantage as well as allowing better metrics to be used when assessing weapon alternatives or comparing weapon platforms.

In addition to the engagement geometry, the miss distance distribution can have a major influence on the probability of a successful engagement. Therefore, the requirement is for:

1. A means of estimating the miss distance distribution for various engagement conditions, and,
2. A means of estimating the probability of success for various terminal conditions and miss distance combinations.

Both miss distance and probability of kill display some variation due to random effects. The usual method of assessing the influence of this uncertainty is to employ a Monte Carlo method. This requires a large number of simulations to be run. In each run the random variables are determined by sampling from the appropriate probability distributions. The simulation results obtained provide information needed to characterize the variables of interest. The statistics of interest are typically the mean and standard deviation. For the problem considered here the information required is the variation of both the miss distance and probability of kill with changes in engagement parameters. To produce this information a Monte Carlo process would employ six degree of freedom simulations of the missile and target to determine terminal engagement conditions, and a model of the target detection device (TDD) to determine the point of burst, and finally a terminal effects suite to determine the effectiveness of the warhead. In many instances the computing overheads

and model complexity make such an approach unfeasible. Another complicating factor is that for some weapon systems not all of the information needed to construct detailed models is readily available. An alternative approach is needed that can be readily implemented and which gives greater insight than a flyout model into the variations that could be expected as terminal conditions and miss distance change. This alternative approach has become known as a Greyscale assessment.

A flyout model has representations of the translational motion of both the missile and the target. It is capable of providing good estimates of missile velocity and approach angles as well as range at intercept and missile time of flight. However, a flyout model does not have a representation of the missile rotational motion and as a consequence does not represent the transitory response of the missile to random disturbances or target manoeuvre. It is the transitory response to disturbances and manoeuvre during the final seconds before intercept that is the major contributor to miss distance. The Greyscales concept is to provide approximate estimates of miss distance and probability of kill of a guided missile against a target as a function of the intercept conditions which are obtained from a missile flyout model. The aim is to provide a process that ensures consistency and repeatability and that allows meaningful comparisons to be made. In many cases the comparison will result in a ranking or ordering of options rather than an assignment of numeric values. For example, an assessment of a variety of engagement conditions may lead to the conclusion that certain tactics give a significant advantage over others but it may not be possible to quantify the improvement in terms of an x% improvement. Hence the choice of the words "Greyscales assessment" was made to describe this capability.

In addition to consistency and repeatability of results other requirements are that the Greyscales procedures must:

1. define the process used to produce miss distance and lethality data
2. allow for a rapid assessment of new weapons
3. allow for upgrading of results when better information becomes available
4. allow flexibility in the way miss distance and warhead lethality are calculated
5. provide a stand alone assessment capability with graphical display of results
6. allow integration into a variety of simulations from one against one to many against many, and
7. define requirements and procedures for documentation

The level of flexibility envisaged is illustrated by the methods that might be used for estimating miss distance:

- Simulation using a model that has representation of the translational and rotational motion of the missile :- usually referred to as a 5 or 6 degree of freedom simulation
- Extrapolation using trials and exercise data
- Manufacturer's analysis
- Estimation by analogy, and
- Use of missile design methods

In addition warhead lethality estimates might be made using:

- One of several warhead/target interaction computer models (two such models are described later)
- Manufacturer's analysis
- Extrapolating trials data, and
- Simplified Lethality/Vulnerability methods

Once estimates of both miss distance and warhead lethality are available they must be packaged into a software component that can be incorporated into larger simulations. The function of this component is to take the terminal conditions for a specified missile and target engagement and calculate a miss distance estimate and a probability of kill estimate which can be provided to the larger simulation. The software component is known as the Greyscales component.

3. Investigation of Miss Distance

3.1 Methods for Determining Miss Distance

The Greyscales miss distance estimate is given as a circular error probable (CEP). The CEP is a radius normal to the nominal missile approach direction which describes a circle that contains 50% of the missile approach paths. Greyscales employs either an algorithm obtained by fitting a curve to miss distance data or a table of miss distance data. There are three ways of obtaining miss distance data for Greyscales.

1. results from detailed missile models
2. results of trials and experiments, and
3. results from analysis using missile design tools

Depending on the particular missile being studied one method or a combination of them may be used.

For most guided missiles a verified 5 or 6 degree of freedom simulation model is the most flexible and most reliable means of estimating miss distance. The most useful model of this type is one that has been independently verified and validated. The validation can be conducted by comparison with trials data and other testing methods, such as hardware in the loop testing.

Trials data are usually limited to small test matrices. The targets may not be fully representative of real targets, and not all the test conditions may be recorded. The trial results by themselves may be insufficient to allow extrapolation. Similarly manufacturer's data may be limited and restricted to those engagements where the missile performs well. However, such information may be combined with knowledge of similar types of missiles to calibrate miss distance estimates obtained from a generic missile model.

The methods used in missile design studies are usually good enough to allow comparisons with other missiles of the same type. These design methods evaluate a conceptual missile in which the missile design is treated parametrically. Although some of the missile

subsystems may be approximated or replaced with generic representations these methods still provide a powerful means of estimating miss distance.

3.2 Selection of Parameters to Characterise Miss Distance

Detailed missile models were used to investigate what parameters influenced miss distance for both infra red and radio frequency guided missiles engaging aircraft targets. A key consideration when conducting this miss distance investigation was to identify a set of parameters that even basic missile models can provide. This was necessary because in many simulations the missile representation is not highly detailed and is capable of providing only limited information on the missile and system states at engagement.

The investigation led to the selection of closing velocity, target velocity, missile velocity, engagement altitude, missile 'g' capability (maximum acceleration possible) and target manoeuvre acceleration (target 'g') as the basic parameters to determine miss distance estimates. These parameters are determined as terminal engagement conditions (i.e. at intercept) and can be obtained from a missile flyout simulation model.

4. Warhead lethality Estimates

4.1 Methods for Estimating Warhead Lethality

A common approach to estimating warhead lethality is to develop a vulnerability model of the target that describes the 3D shape of the target, the materials and thickness of the outside panels and the internal structures. The location of each component is determined and its characteristics described so that its vulnerability to the various damage mechanisms can be determined. In addition fault trees or their equivalent are determined. A fault tree identifies which target components or sub systems are essential for various functions. A fault tree also identifies which individual components or combinations of components must be damaged to achieve certain engagement outcomes. An example of an engagement outcome would be causing sufficient damage to the attacker to cause a mission to be aborted. The development of target vulnerability models can take up to a number of months depending on the complexity of the model and the level of detail in the information available.

In parallel the warhead characteristics are characterised. This procedure provides the data needed to describe the capability of the warhead damage mechanisms. The damage mechanisms of interest in Greyscales are primarily blast and fragment strike.

The missile target detection device is also characterised. It is necessary to determine the relative positions of the warhead and target at the time of detonation. This requires knowledge of the TDD characteristics and how it detects and reacts to the presence of the target. A TDD may be represented by a geometric model which describes the range and look angles of the TDD. These data can be used to determine when the TDD first "senses" the target and when the TDD will initiate detonation. More complicated TDD models may

require more information on the target materials, surface shape etc to determine when detonation occurs. A simplified TDD model may be incorporated into the lethality estimating code.

On completion of these steps a lethality estimating code can be executed to provide estimates of the probability of damaging the target for a variety of engagement conditions. Examples of lethality estimating codes are INTAVAL developed in the UK and XVAM originally developed in Canada and further improved in Australia. While these codes have some features in common there are significant differences. One major difference is some codes assume that detailed modelling of fragment/component interactions can be replaced by a combination of mean values and statistical distributions in some calculations. In contrast other codes require the exact location of each component and individual fragment paths are traced to find which components a fragment will strike and possibly pass through. The outputs of both of these types of model are estimates of probability of achieving a specified level of damage by the warhead against the target.

An alternate approach is to use detailed models to produce the response of a target to various damage mechanisms, such as fragments of a given size and velocity. These data are processed to produce such measures as tables of vulnerable area and lethal radii. This approach gives the data required to estimate the probability of kill of a target by a given warhead and kill criterion. The JMEM vulnerability methods developed in the USA employ this approach.

Any of these methods may be used to estimate the probability of a given warhead damaging a target. However, as mentioned in the introduction there are occasions when other more approximate methods are appropriate. Some of these alternatives are appropriate when time constraints or lack of data prevents detailed model construction.

4.2 Selection of Parameters to Characterise Warhead Lethality Estimates

Any of the above mentioned methods may be used to generate the warhead lethality data. In Greyscales the parameters used to characterise the probability of kill are independent of the lethality method used.

These parameters are:

- The warhead approach direction as given by the angles between the target velocity and the missile velocity in target centred axes. The approach direction is given by an azimuth and an elevation angle.
- The missile velocity and the target velocity.
- The miss distance as given by the circular error probable (CEP)

5. The Greyscales Component

The underlying philosophy of the Greyscales component is that it must be able to be integrated into various simulation environments. As mentioned above, Greyscales is

dependent on miss distance data and on probability of kill data. These data are contained in a Greyscales data file. A Greyscales data file is required for each missile/target combination. To be more precise data is needed for each missile/target/target manoeuvre/kill criterion combination. Currently there is only one manoeuvre for air targets:- a single plane turn initiated at a random time before intercept. There is also only one kill criterion for each target. The details of the file structure and the other input requirements of the Greyscales component are given in reference 1.

For a given combination of missile and target Figure 1 below illustrates the Greyscales component and the input parameters

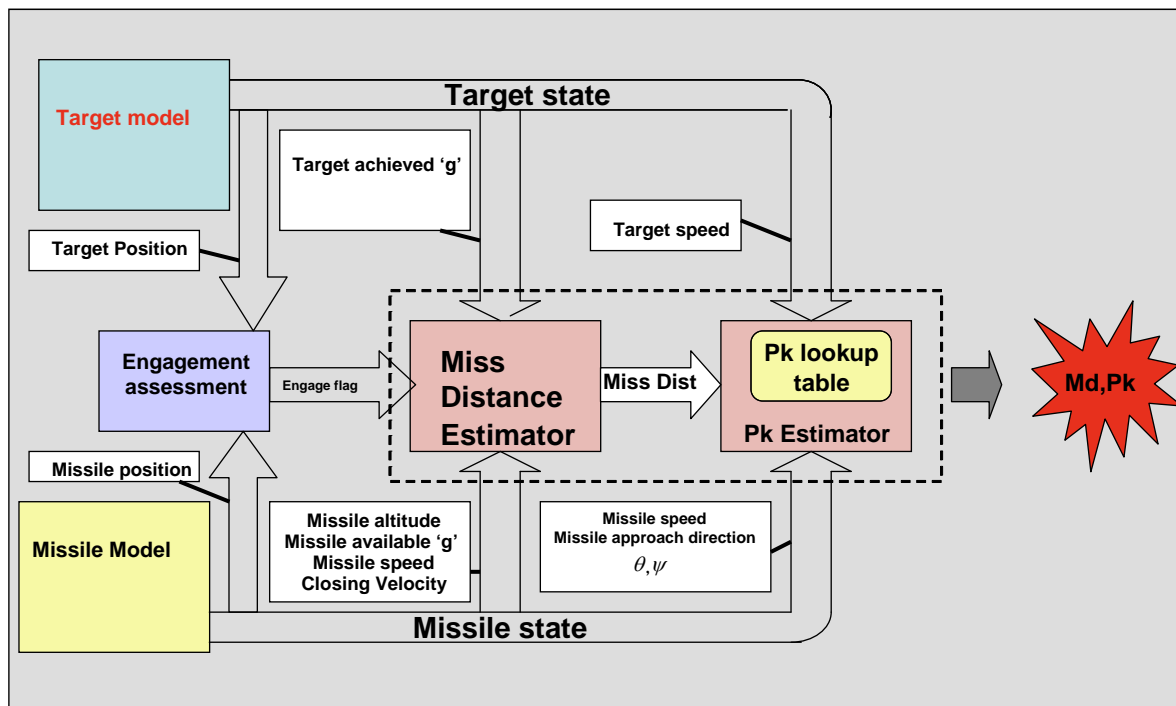


Figure 1 Greyscales component and input parameters

In the above diagram the target model and the missile model are capable of determining the trajectories of the target and missile and providing the necessary input data for the miss distance and lethality estimators. The Greyscales component is enclosed by the box drawn with broken lines.

6. Procedures for Determining Miss Distance Estimates

For each missile/target combination the Greyscales data file contains the miss distance information. This information can be either in the form of a table or an algorithm to calculate the miss distance estimate. If a table is provided the Greyscales software

interpolates to produce the required miss distance estimate. If an algorithm is used to estimate miss distance, the functional form can be different for each data file; however, the independent variables must be combinations of the input parameters given in section 3.2. At present the miss distance algorithm is determined using an open source curve fitting package.

If an algorithm is used a set of miss distance data is required to perform the curve fitting. In order to achieve a good estimate of miss distance engagement scenarios it is desirable to include head on, crossing and tail on engagements for each target as well as a range of altitudes, target and missile velocities and target manoeuvres. The source of the miss distance data can be any of the methods already mentioned (experiments, trials, 6DOF etc). Figure 2 below illustrates the process for generation of Greyscales miss distance data. At this time detailed simulations have been employed to generate miss distance for some missiles and an adjoint method (references 2 and 3) has been used for others when a detailed missile simulation model has not been available. It should be noted that the adjoint method employs a linearized set of equations. This means engagements are either nearly head on or nearly tail chase and no limits, for example maximum fin deflection, can be represented.

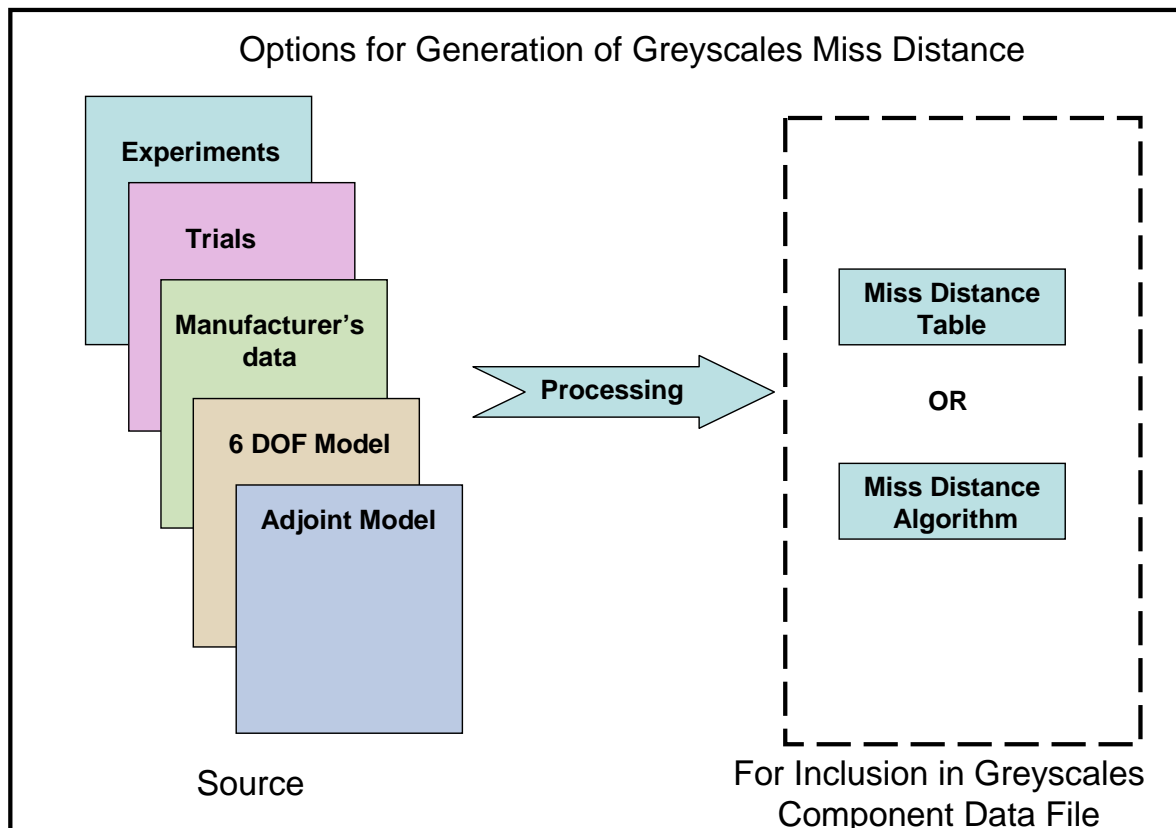


Figure 2 Options for generation of miss distance data

7. Procedures for Determining Lethality Estimates

The Greyscales component employs a lethality estimate lookup table that is included in the Greyscales missile /target data file. The data that populates the table must be calculated using standard warhead lethality methods. The estimates of warhead lethality for one kill criterion are required for approach directions in 45 degree increments in both elevation and azimuth (26 in all) for a range of missile circular error probable values (CEPs) and for a range of missile closing velocities. At present the XVAM lethality estimation package is used for this purpose. However, as shown in Figure 3 below other methods could be used to generate the probability of kill data.

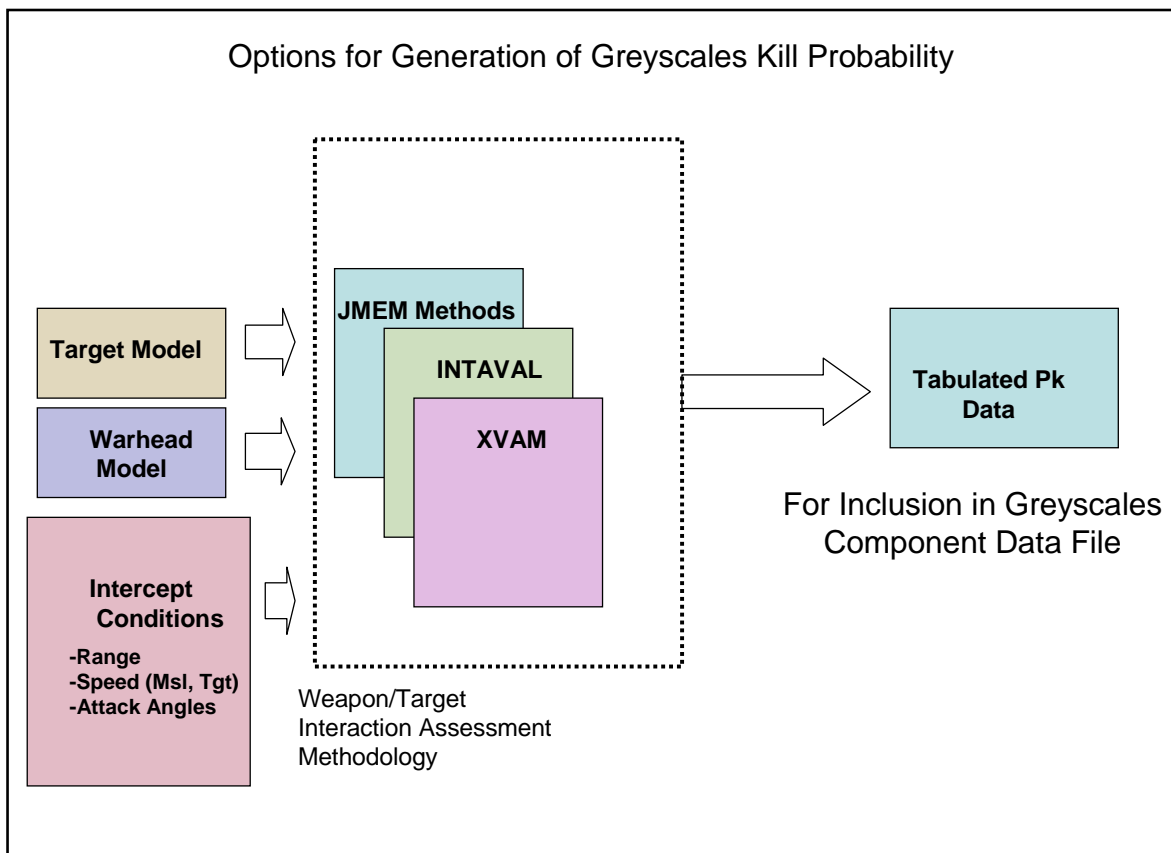


Figure 3 Options for generation of kill probability data

8. Summary and Conclusions

This technical note provides an overview of the Greyscales method for estimating missile miss distance and probability of kill. The method provides an intermediate step between a simple missile flyout model and the considerably more complex and detailed models of missile and warhead behaviour. Two of Greyscales major characteristics are:

1. the method allows a lot of flexibility in source data, and,
2. the software can be integrated into a variety of simulations of varying complexity.

Greyscales was initially envisaged as a means of facilitating comparisons between competing missiles or missile concepts. However, it is hoped that Greyscales will prove to be valuable for other applications such as evaluation of system performance or as an aid to developing tactics.

While this note has focussed on the Greyscales method it should also be noted that the associated software and the processes for the production, upgrading and distribution of Greyscales data files and software represent a significant proportion of the Greyscales activity.

For those interested in using the Greyscales software component other publications that contain the necessary detailed information are available.

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA					
				1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)	
2. TITLE An Overview of the "Greyscales" Lethality Assessment Methodology			3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) <div style="display: flex; justify-content: space-between;"> Document (U) </div> <div style="display: flex; justify-content: space-between;"> Title (U) </div> <div style="display: flex; justify-content: space-between;"> Abstract (U) </div>		
4. AUTHOR(S) David Thomson			5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation PO Box 1500 Edinburgh South Australia 5111 Australia		
6a. DSTO NUMBER DSTO-TN-0982		6b. AR NUMBER AR-014-903		6c. TYPE OF REPORT Technical Note	
7. DOCUMENT DATE January 2011					
8. FILE NUMBER 2010/1006488/1		9. TASK NUMBER AIR 07/046		10. TASK SPONSOR PM NACC	
				11. NO. OF PAGES 22	
				12. NO. OF REFERENCES 3	
13. URL on the World Wide Web http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0982.pdf			14. RELEASE AUTHORITY Chief, Weapons Systems Division		
15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT <p style="text-align: center;"><i>Approved for public release</i></p>					
OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111					
16. DELIBERATE ANNOUNCEMENT No Limitations					
17. CITATION IN OTHER DOCUMENTS Yes					
18. DSTO RESEARCH LIBRARY THESAURUS http://web-vic.dsto.defence.gov.au/workareas/library/resources/dsto_thesaurus.shtml Weapons effects, simulation. Miss distance, kill probabilities					
19. ABSTRACT Greyscales is a method for producing estimates of guided missile miss distance and missile warhead probability of kill. The associated computer code has been written to be portable and capable of being incorporated into a variety of simulations. The code has already been integrated into the Weapon Systems Division MECA and DUEL missile engagement simulations. It can also be integrated into larger scale simulations where multiple engagements between various platforms are represented. Greyscales provides an improved means of assessing missile/target engagements without resorting to computationally intensive missile and warhead/target interaction models. This brief report describes the greyscales approach.					